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Susanne Jakob
Dipl.-Ing. Helge Drumm

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M. Muhr, S. Pack, R. Schwarz, S. Jaufer

# Calculation of Overhead Line Sags

**Power Engineering**

**Abstract:** The liberalisation of the energy market in Europe leads to change in operation of the transmission network. Diagnostic tools for the condition evaluation get more importance. Based on the changed stress and the large expansion of the network of the line components a considerable effort for condition evaluation and maintenance is necessary.

In the centre of Europe the Austrian transmission line system at the level 230kV and 400kV has an important role for the energy exchange and was built up in 50's to the70's of the last century, therefore parts of the system are more than 40 years old.

Based on this situation this paper focuses on the operation behaviour of ageing overhead lines with special regard to the sag calculation of span sections.

The sag of a transmission line will increase by increasing conductor temperature caused by the electrical load and specific environmental conditions or additional rope forces (e.g. ice load). In addition, the permanent mechanical forces (everyday stress) elongate the conductor irreversible during its live time.

**Key Words:** Overhead line, Aging, Sag, Calculation

## INTRODUCTION

Overhead lines are the backbone in every electrical power transmission system. Because the consumers are not concentrated at the location of the generation it is not possible to use power plants with high output. For the connection between the power plants and the consumers integrated network consists of transmission line systems like overhead lines or power cable are in use.

In the past the regional operators worked together, electric energy was generated nearby the consumer and the network was used as back up. Today by the liberalisation of the European energy marked the trading at the spot marked gives the power flow. So the transferred electrical power varies over the transmission lines. In addition, the cost pressure is increasing, and the grid operators have to save investments to make their transmission lines most economical. Therefore, they use their lines near the nominal limits and the maintenance strategy has changed from a time based to a condition base strategy. For the usage of an overhead line, the ground clearance of the ropes is one of the important parameters, because a safety margin has to maintain over the whole expected useful life [7].

In general, the conductor elongates by the permanent mechanical forces (everyday stress) during its live time. Additionally to this irreversible elongation, the sag of a transmission line will increase by the conductor temperature caused by the electrical load and specific environmental conditions or other conductor forces (e.g. ice load).

## ELONGATION MECHANISM

The sag curve of a conductor, which is spanned between to points, is depending on the distance between the fixed points and the tension in the conductor and can be specified by the funicular curve. The always presented wire tension is variable by the wire temperature and the additional load. This permanent stress leads to an irreversible elongation. Additional the elastic and thermal elongation occurs, depending of used wire materials. Mostly high conduction aluminium as conductor and a high strength material as mechanical support (steel, aldrey) are used. For the common type ACSR overhead lines, galvanize steel wires used as support. The composite of this two material with different material properties leads to an average behaviour of wire. So the mechanical tension is not equal during mechanical stress in aluminium and steel.

The lower elasticity module causes a lower tension in the aluminium than in the steel. Based on this circumstance the load distribution is also different depending on the construction and the strength of used materials as shown in Table 1.

**Table 1: Load distribution of different conductor types**

| | Area ratio | | | | |
|---|---|---|---|---|---|
| Al/St | 1:1 | 3:1 | 4:1 | 6:1 | 11:1 |
| Al | 22.5% | 45.5% | 53.7% | 65.3% | 76.1% |
| St | 77.5% | 53.5% | 46.3% | 36.5% | 23.9% |

In addition, the different thermal expansion of the used material leads to a thermal influenced changing of the load and tension ratio. Aluminium has a higher thermal expansion coefficient than the used steel.

Under this circumstance during increasing temperatures the aluminium is released and the steel core will get a higher mechanic load. At a certain temperature called knee-temperature, the steel core will carry the whole load and the aluminium has no mechanic load anymore. This temperature depends on the mechanical structure of the ACSR conductor. In Figure 1 some examples are shown.

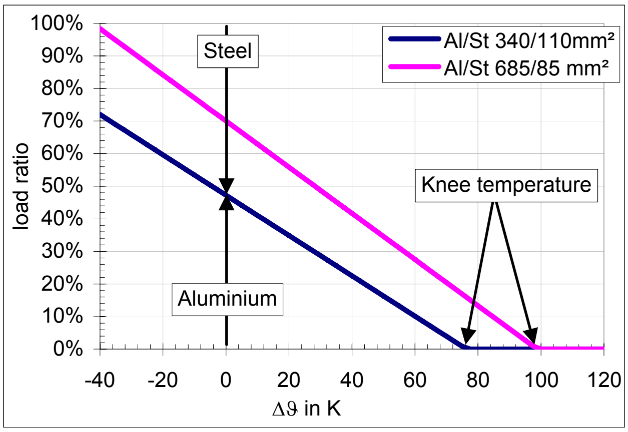


**Fig. 1: Thermal behaviour of the load ratio**

## AGING EFFECTS

The low melting point of aluminium with a level of 660°C leads to a creeping of overhead lines [1] [2] [3] at the normal operating temperatures. This creeping is also temperature depending and will increase at higher temperatures. Influence parameters for this creeping are the mechanical structure, the conductor tension, the maximum mechanical load and the temperature.

Due to missing monitoring systems for overhead lines for most existing lines conductor temperatures or maximum loads are not available. For a new line, the measurement effort for the monitoring is very high and expensive. So it is easier to measure the sag and the conductor temperature in certain intervals to achieve the elongation of the overhead line conductor and the ground clearance [4].

The elongation of the conductor caused by thermal or aging effects has different effects on the sags of a line section.

## OVERHEAD LINE MODEL

In Austria, the length between two overhead line rods is typical between 200 and 350m and depends on the geographic situation. The 400kV network is typical equipped with two or four conductors per phase and the 230kV network with one conductor per phase. The in the calculation used model is based on a typical Austrian overhead line for the system voltage of 230kV and 400kV. Table 2 shows the technical data of the modelled overhead line types.

**Table 2: Conductor data and isolator data**

| | ACSR 340/110 | ACSR 680/85 |
|---|---|---|
| Al area | 341.2mm² | 678.6mm² |
| St area | 108.8mm² | 85.95mm² |
| Weight | 1815kg/km | 2564kg/km |
| Modulus of elasticity | 8400daN/mm² | 6800daN/mm² |
| E-modulus Al | 6000daN/mm² | 6000daN/mm² |
| E-modulus St | 20700daN/mm² | 20700daN/mm² |
| Coeff. of linear expansion | $1.67\ 10^{-05}K^{-1}$ | $1.94\ 10^{-05}K^{-1}$ |
| Isolator type | 2 long rods | 3 long rods |
| Weight (tension/suspension) | 130/60kg | 240/180kg |
| Total length (tension/suspension) | 3.5/2.85m | 6.7/5m |

Two different rod arrangements for a flat terrain were calculated:

1. Symmetric rod distribution (free flat terrain without rivers, roads or building)
2. Asymmetric rod distribution (realistically situation in flat terrain with hindrances).

## CASE STUDY 230KV SYSTEM

Overhead lines with symmetric and asymmetric rod distribution in a flat terrain are calculated in this case study. The mechanical construction represents a typical Austrian overhead line of the 230kV network with an ACSR 340/110mm² conductor.

The initial state for the sag calculations is shown in figure 2. The horizontal forces are in each span equal at this temperature and so the suspension insulators (T1...T4) hang perpendicular. The tension insulators (AB1 and AB2) will be linked depending on their own weight and the conductor forces.

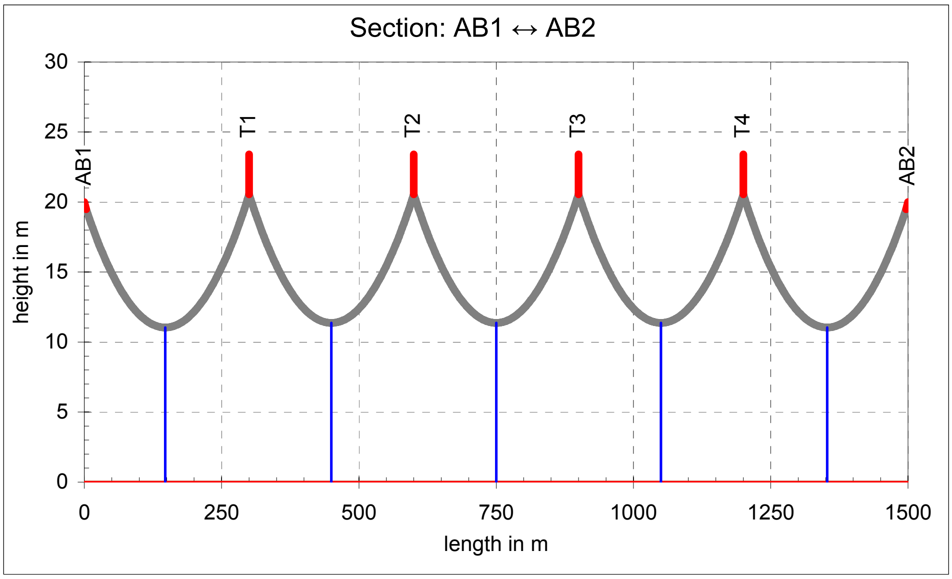


**Fig. 2: Initial state at 10°C conductor temperature**

During the load current, the conductor temperature will increase so the sag will increase too, as shown in Figure 3.

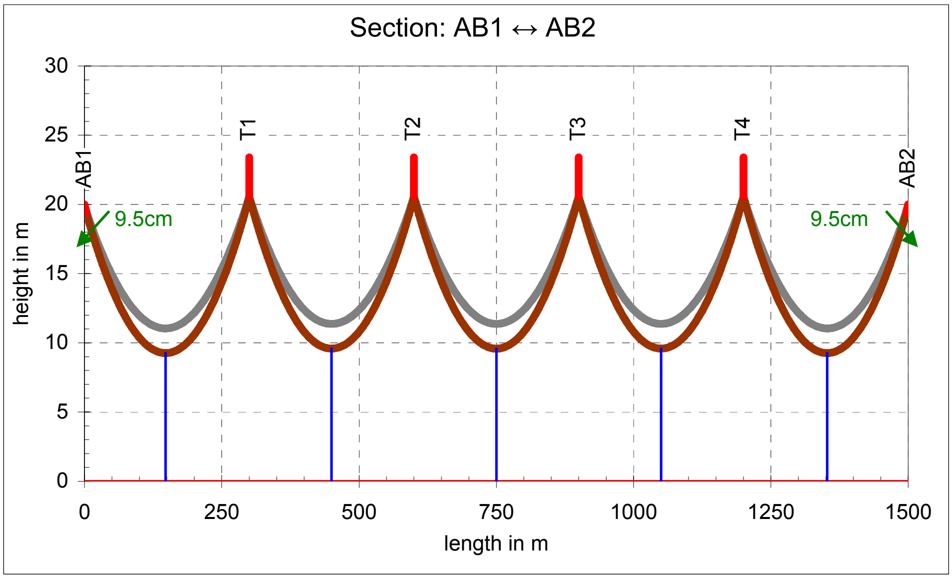


**Fig. 3: Sag calculation at 80°C without elongation**

Caused by the temperature rise, the horizontal forces in the conductor will decrease (-16.2%). Additional the clamping points at the end of the tension insulator are lowered at 9.5cm. This system has now an inhomogeneous horizontal force distribution with is linked by the suspension insulators. Their deflections are insignificant and have small effect. A significant effect on the sag has only the deflection of the tension insulators. In this case study, an elongation caused by the everyday stress of 0.336‰ and 0.435‰ was assumed which will accords an used period of 50 and 120 years. According to the elongation, the sag increases in all spans about 0.47÷0.6m (see Figure 4).

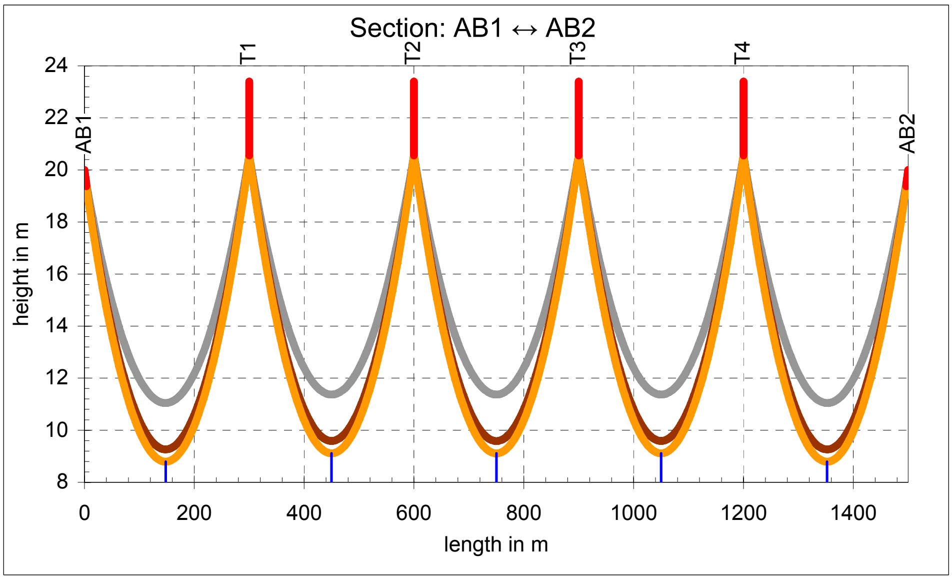


**Fig. 4: Sag calculation at 80°C with elongation (0.336‰ – 50years)**

In figure 5, the initial case with asymmetric rod distribution with the same overhead line conductor is shown. A heavy asymmetrical rod distribution (minimum 200m, maximum 400m) is the basis for the calculations.

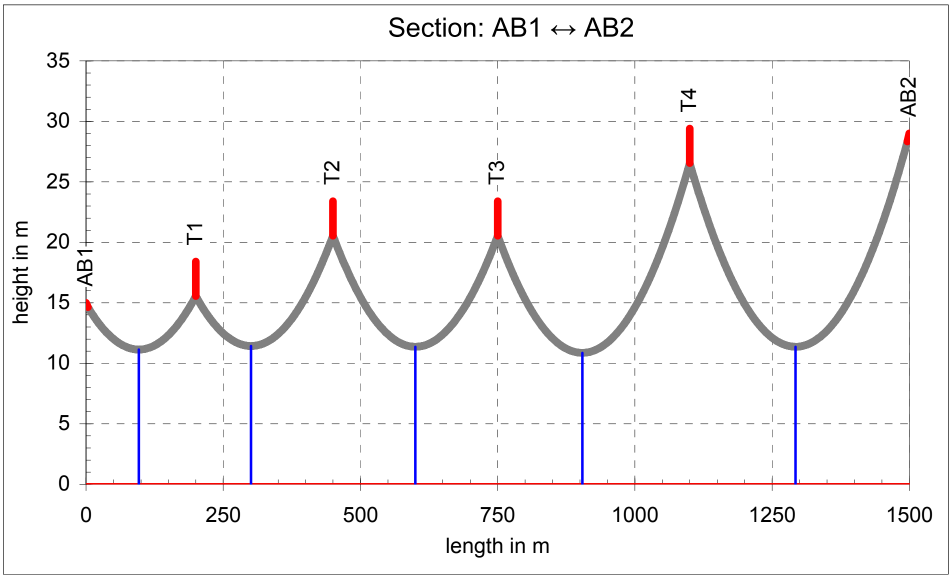


**Fig. 5: Initial state at 10°C conductor temperature**

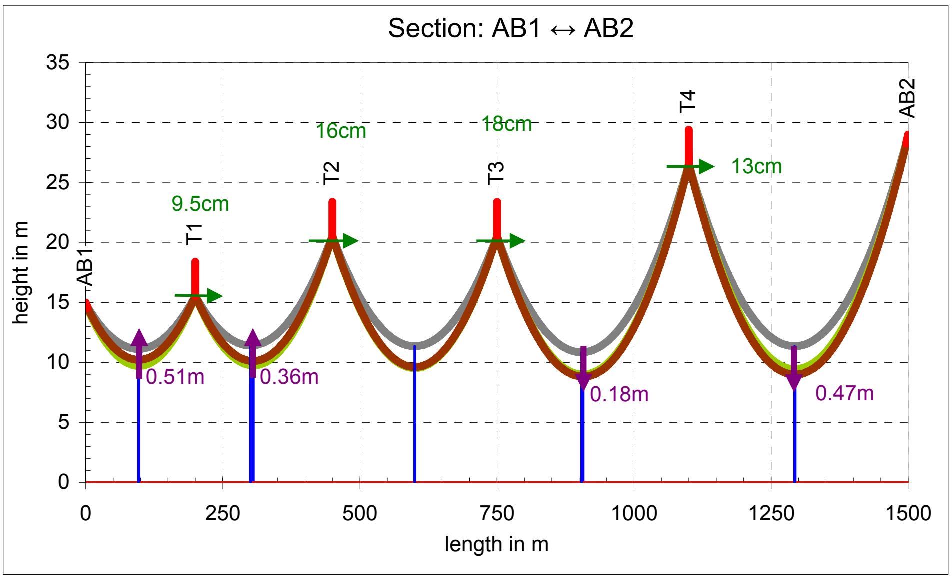


**Fig. 6: Sag calculation at 80°C without elongation with and without suspension insulator deflection**

The sag will increase unequal as shown in Figure 6 by rising conductor temperatures. Similar to the symmetrical rod distribution, the tension insulators shows a deflection about 10cm. In addition, all suspension insulates have now a significant deflection pointing to the span with the greatest distance between the mounting. With this deflection, the sags of the short spans are reduced and the longer spans will increase.

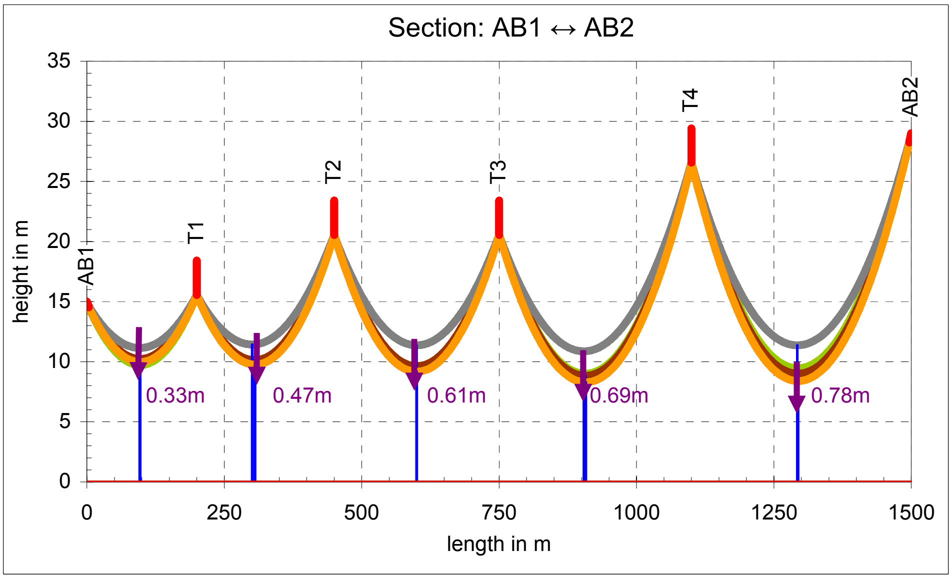


**Fig. 7: Sag calculation at 80°C with elongation (0.336‰ – 50years)**

In Figure 7, the identical elongation is assumed as in the prior examples and the sag increases by elongation about 0.26÷0.78cm asymmetric depending on the span.

## CASE STUDY 400KV SYSTEM

A 400kV overhead line with an ACSR 685/85mm² conductor is modelled in this example. The rod distribution is the same as in the 230kV case.

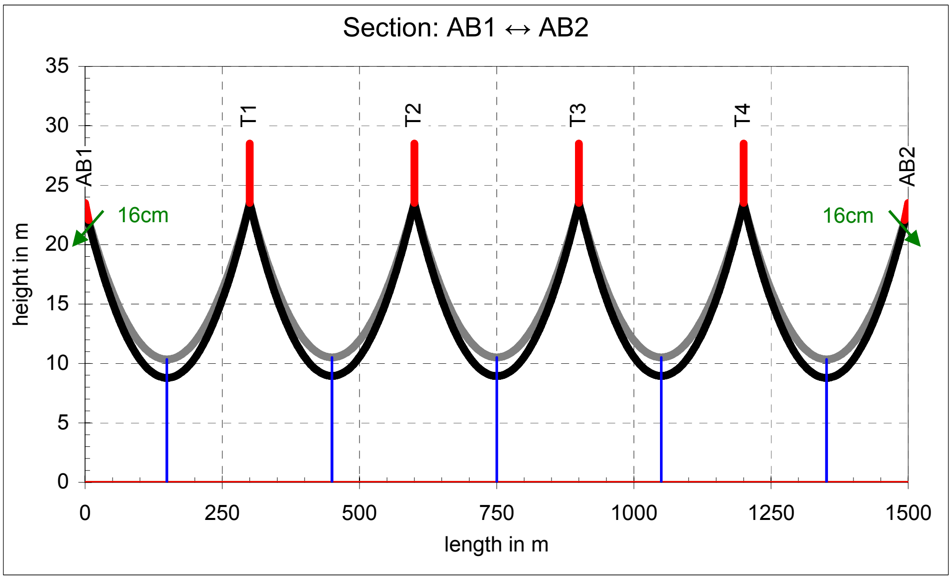


**Fig. 8: Initial state at 10°C conductor temperature and sag calculation at 80°C without elongation**

The deflection in this model is higher than in the 230kV example with the longer and heavier tension insulators. The suspension insulators are neglect able deflected. The temperature caused sag increase is now lower than in the previous case study (1.57m than 1.78m). The lower elastic modulus is the reason for this circumstance and compensates the higher coefficient of linear expansion of the ACSR 685/85mm² conductor. By the lower steel fraction, the elongation is higher than at the ACSR 340/110mm² conductor. According to an age of 20, 50 and 120 years, an elongation of 0.331‰, 0.435‰ and 0.567‰ was assumed. Depending on the age, the elongation sag increase is in a region from 0.36÷0.62m.

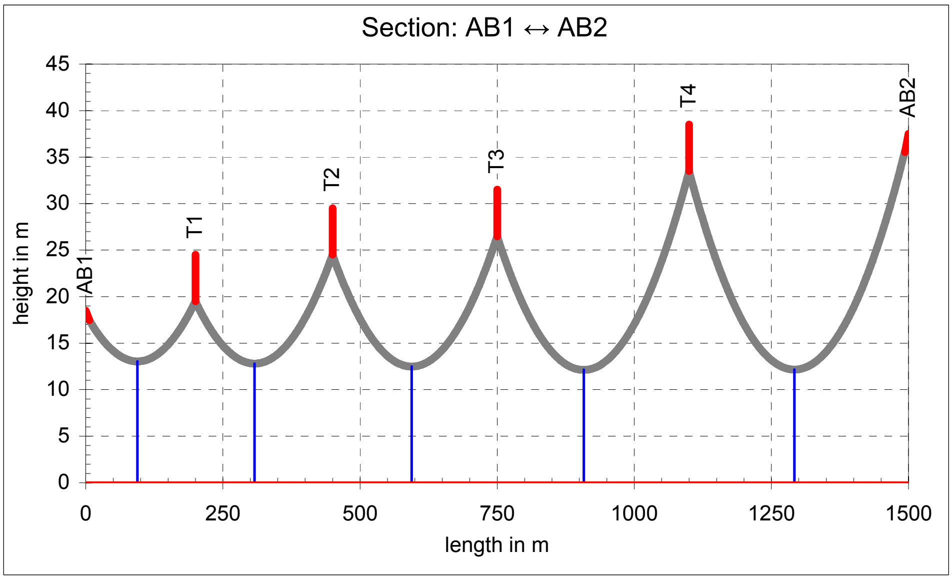


**Fig. 9: Initial state at 10°C conductor temperature**

An asymmetric rod distribution is shown in Figure 9. The sag is increasing asymmetric with rising the temperature and the suspension insulators deflect as shown in Figure 10.

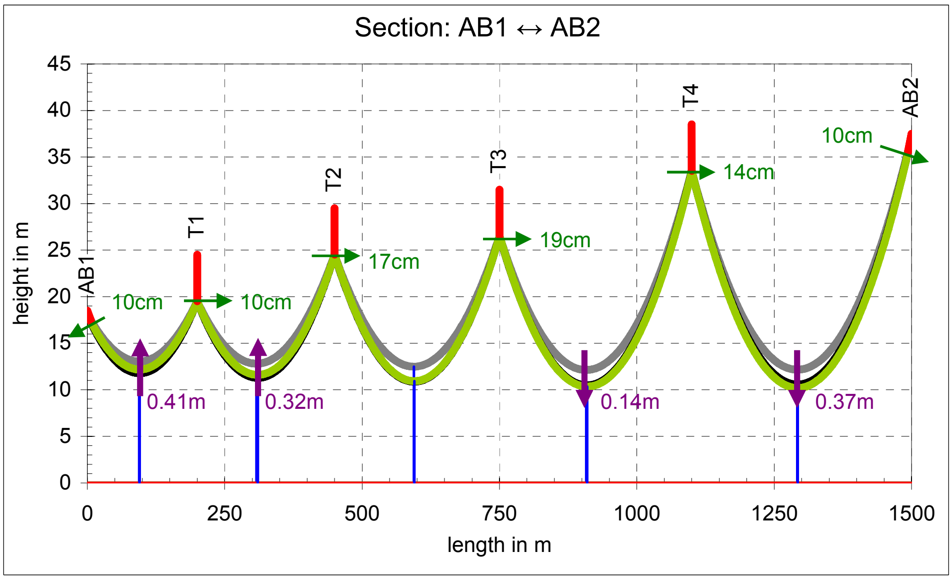


**Fig. 10: Sag calculation at 80°C without elongation, with and without suspension insulator deflection**

The effect of the deflection of the suspension insulators is marginal lower than at the ACSR 340/110mm² but big enough to affect the sag calculation.

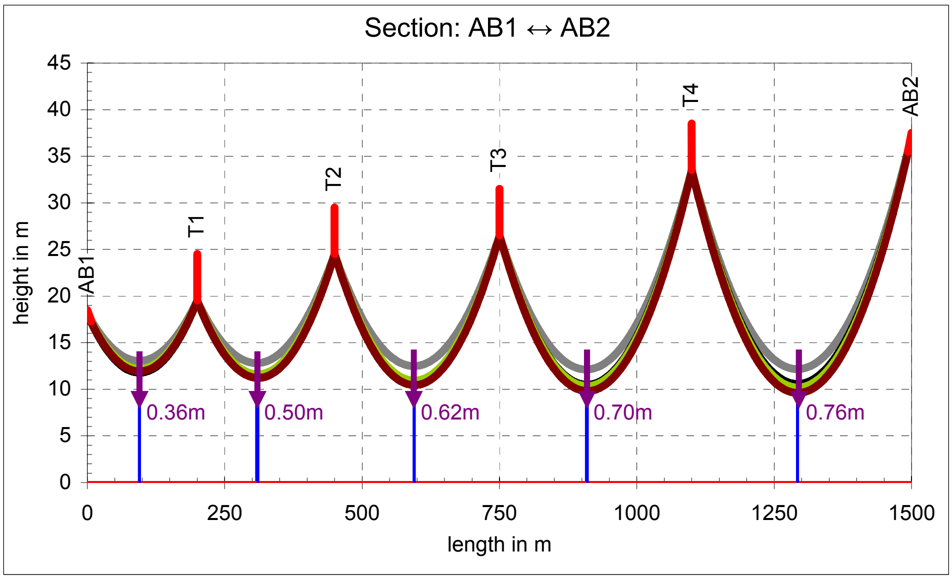


**Fig. 11: Sag calculation at 80°C with elongation (0.435‰ – 50years)**

With an aging depending elongation the sags increase from 36cm to 76cm depending on the span dimensions of the modelled overhead line.

## Conclusion

In this paper, sag calculations of two different overhead lines are presented. The results show, that the sag behaviour of the close-by spans is affected by the deflection of the tension insulators. The deflection of the suspension insulators is negligible in a symmetrical rod distributed flat overhead line, and has insignificant effects on the sag calculation. In an asymmetrical rod distribution case the deflection of the suspension insulators is not negligible. The sag of the span with the largest distance between the rods will increase much more than in smaller spans. The safety distance will reduced by the elongation of the overhead conductors.

In this example, the sag will increase in magnitude of 26 to 78cm by aging elongation. This effect can be compensated by a reduction (approximate 28K) of the conductor steady-state temperature. The transmission capability is also reduced by the lower permissible conductor temperature [5] [6].

This capability limitation may cause negative effects on the power quality especially in the hot summer time.

## SUMMARY

In this case study, based on typical Austrian overhead lines of a 230kV and 400kV system voltage, a sag calculation was carried out.

The most important result of the calculations is that the deflection of the suspension insulators affects the sag in the case of an asymmetrical rod distribution. With symmetrical distribution, only defection of the tension insulator affects the result. An aging depending sag increase is caused by the elongation of the overhead conductors due to the everyday stress.

Based on this circumstance, a safety reserve for the phase to earth clearance must be considered for the planning and construction.

The reliability of an aged overhead line can be improved by sag verification with can be done by measurement or calculation. So depending on the system voltage and the object type, the minimum phase to earth clearance can be assured.

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**Authors:**

Michael Muhr, Dr. techn, Univ.-Prof.
Stephan Pack, Dr. techn, Univ.-Prof.
Robert, Schwarz, Dr. techn, Ass.
Stefan Jaufer, Dipl.-Ing., Wiss.-Ass.
Institute of High Voltage Engineering and System Management
Graz University of Technology,
Inffeldgasse 18,
8010 Graz, Austria, Europa
Tel.: +43/ (0)316/873-7400
Fax.: +43/ (0)316/873-7408
Email: surname@HSPT.TU-Graz.ac.at